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THE SMUT DISEASE OF ONIONS

By P. J. Anderson and A. Vincent Osmun

This bulletin records six years' experiments on the control of smut, the most destructive disease of onions in New England and presents practical recommendations based on these experiments. It also includes an account of the origin, history and economic importance of the disease and the development of the causal organism.

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INTRODUCTION

Commercial onion growing in Massachusetts sixty years ago was confined to the eastern part of the state, centering especially in Essex county about the Danvers section. But continuous cropping brought diminishing yields year by year until the growers found that they could no longer produce a profitable return on onions even in that fertile section. New land must be found, and the industry shifted gradually to the west until now practically all of the Massachusetts domestic supply of surplus onions is produced in the Connecticut Valley. The fertile acres of the Danvers section, famous onion center since colonial days, are no longer planted to onions.

When we inquire into the reasons for the diminishing crops and the westward shifting of the industry we find that the most important contributing factor was the increase in the prevalence and destructiveness of smut until the toll which it took wiped out the profits. A field once thoroughly infested with smut was permanently eliminated from profitable onion growing, and since no method of checking the disease had been discovered at that time, the inevitable result was the migration of the industry from a section so largely planted to onions.

The Connecticut Valley region, however, did not long escape. Year by year, smut became more prevalent; fields were being planted to other crops and the history of Danvers was in a fair way to be repeated along the Connecticut, when the formaldehyde method of controlling smut was discovered and the industry saved for the Valley.

But the formaldehyde method as worked out by the pathologists of twenty years ago was far from satisfactory. The formulas of application which they recommended were cumbersome and the machinery inadequate. The writers were unable to find a single grower in the Connecticut Valley who was applying the formaldehyde according to the rates of dilution and distribution which were recommended by the pathologists. Finding these inconvenient, the practical growers modified them in various ways to suit themselves. The results obtained were more various than the rates of application. Some were successful; many had partial control; others ruined the crop. Lack of uniformly successful results caused many to condemn the method and either to plant the fields to less profitable crops or to omit the formaldehyde and tend the onion crop at a reduced profit or an actual loss.

Such was the situation when the writers began their investigation of onion smut in 1918. The whole field of control seemed ripe for a reworking.

It was necessary that a formula of applying the formaldehyde be determined and standardized for Connecticut Valley conditions, a formula which should be practical for the grower and at the same time could be depended on to control the disease and not cause serious injury to the onions. The machine for application must be improved. The behavior and life-history of the smut fungus throughout the whole year must be carefully studied with the special object of finding a better method of combating the disease. Many other minor problems were yet unsolved.

During the last six years the investigation has been prosecuted in the laboratory and greenhouse during the winter and in the fields of the onion growers of Sunderland, Amherst and Leverett and on the Experiment Station farm during the growing season. It was essential that the field control experiments be continued through a series of years on different farms because it was found that the season and other

environmental conditions influenced the results of the treatment and it was desirable to develop a method which would be suitable for every year under a wide range of conditions. The writers believe that after six years of experimenting they are ready to publish definite recommendations. In the present bulletin there are also presented the experiments and data on which the recommendations are based, along with the results of some other accessory lines of investigation on onion smut.

HISTORY OF THE DISEASE

Onion smut is probably a disease of American origin, although its history previous to 1857 is unknown. Onions have been cultivated and used by all the civilized races of the world in all ages. Starting with the inscriptions on the pyramids, there is an enormous amount of ancient and modern literature on all phases of onions and onion culture, but it contains no mention of smut or any trouble which might be interpreted as smut previous to the middle of the 19th century, when it was first found in New England. If smut is of Old World origin, this omission is certainly nothing short of remarkable. Is it not more probable that it occurred in an inconspicuous way on some other closely related American plant and thence passed over to the onion which it found to be a more suitable host? To be sure, we have no published record of its occurrence on any other American plant (except for one record of a wild onion, *Allium Nevadense*, in the Far West); but when one recalls that new diseases and new hosts of disease organisms are being discovered every day, and that it may occur on its wild host plant only as an inconspicuous seedling disease, this does not seem to be a serious objection. The fact that the disease has been found on twenty-six other species of plants of the same genus not previously reported as affected by smut (p. 8) indicates that all of the host plants of the onion smut have not yet been found.

The first published record of the existence of onion smut which the writers have seen is in the Proceedings of the Essex Institute for 1857 (31: 207, 211–214)*.

Since this interesting article seems to have escaped the notice of other students of the disease† and is in a rather inaccessible publication we quote it in full. At a field meeting of the society at Beverly, Mass., on June 24, 1857, a letter was read by the secretary from Mr. J. W. Proctor,‡ a Danvers farmer. This letter according to the report of the secretary, Mr. Wheatland,

> "treated of the smut of the onion and of a maggot, which attacks that vegetable, threatening serious injury to the onion crops. He considered that at least half the estimated crop of the present season would be lost. This letter was referred to a committee consisting of Messrs. S. P. Fowler, George D. Phippin, and Henry F. King, in order that it might make the necessary investigation, and report on the subject at some subsequent meeting of the Society."

At the next meeting, which was held at Wenham on July 10, 1857, Mr. Geo. D. Phippin of Salem, made the following report on onion smut:

> "As to the second agency found so destructive in the cultivation of the onion your committee report that the smut found growing in the leaves of the onion plant has been examined under the microscope; but the specimens used were so imperfect that no information of a decisive character has been obtained. It is evident that the smut of the onion is a parasitical fungus which originates and develops itself within the cellular tissues of the leaves looking in some stages of growth like the filaments of a Botrytis. It makes its appearance on the first leaf and descends toward the root destroying the texture and rendering the leaf spongy and streaked with a black dust. Perhaps then it may originate from the use of too much putrescent

*Numbers in parenthesis refer to bibliography in the back of this bulletin. Numbers after the colon give the page on which statements referred to may be found.

†All the writers on onion smut who have mentioned the matter at all (Farlow, Thaxter, Stone, Walker, Cornu, *et al.*) quote as the first published record, the observation of Ware (51), 12 years later. Probably a more thorough search through the agricultural literature of Essex County just previous to 1857 would reveal earlier allusions to smut.

‡Ten years previous to this date Mr. Proctor, who appears to have been an onion grower of considerable prominence, presented "An Essay on the Cultivation of the Onion" before the Essex Agricultural Society (33) in which he gave considerable attention to the pests and enemies of the onion, but no mention is made of smut. The fact that a practical, keen observer like Mr. Proctor had never seen smut leads us to believe that it was not present at that early date in the Danvers section.

matter in the soil, helped toward development by a peculiar low and damp atmosphere. The use of muscle-bed mud for culture of onions is well known but we have not ascertained whether such manuring is liable to the fly or not. An overmanured soil made so by too much putrescent animal or vegetable matters could be treated with lime ashes or charcoal, which by helping to absorb the ammonia would check the fermentary process so favorable to the growing of fungi of every kind.

"It would be interesting to ascertain whether this particular species of smut is to be found upon the leaves of the wild garlic (*Allium canadense*) for it may be that a more succulent condition of the cultivated plant as in our field onion, may be more susceptible to this disease from the high culture which it obtains. Such parasitic plants destructive to crops, indicate the tendency toward extinction of a particular variety, and the remedy may lie in changing the seed or by inducing some newer form not liable to be thus affected."

The next published record of the disease is in the appendix of the 17th annual report of the Massachusetts Board of Agriculture (51:10) in which is printed an address by Mr. Benjamin P. Ware, a Marblehead farmer, before the Essex Agricultural Society on September 29, 1869. He states that smut is "very destructive, turning the most promising fields . . . to scenes of desolation," and that it "so impregnates the land with its spore as to render it unsafe to plant onions for several years on land thus affected." In view of our present knowledge of the long time required for impregnation of the land, these statements indicate that smut was not a new disease in Essex County in 1869, but that it must have existed for many years. There is evidence according to Thaxter (44:131) that it occurred in Connecticut as early as 1860, although there is no published record. In his report of the U. S. Department of Agriculture for 1869 (7:224) the commissioner, Mr. Horace Capron, devotes a page to onion smut, but mentions no locality except Massachusetts. From this, one judges that it was not known to occur in other states at that time. In the U. S. Commissioner's report for 1872, (43:193) Mr. Thomas Taylor, the microscopist, mentions a field of four acres in Swampscott where the disease was so bad that the field was abandoned. In the same report, he published the first figures of onion smut spores. The first accurate scientific description of the disease and its causal fungus is by Farlow (14: 64) in the appendix of the report of the Massachusetts Board of Agriculture for 1876. He states that at that time it was not known to occur anywhere except in Massachusetts and Connecticut and presents convincing evidence that it was of recent origin.

Summing up all the evidence in regard to the origin of smut we may say that in all probability it existed on some native American plant closely related to the onion and first made its appearance on the cultivated species about 1850 in New England.

From New England it has spread to all of the onion-growing regions of the northern United States, but is not known to occur in the southern states. In 1889 it was known to be present in Ohio and Pennsylvania (44:135) and in Vermont (25:141), New Jersey in 1890 (20:352), New York, previous to 1869 (37), Iowa, about 1900, (30:216) and reached the Pacific coast about 1911 (6:187). The date of introduction into other states is not recorded, but at present it is known to occur in Indiana, Illinois, Wisconsin, Missouri, North Dakota, Delaware, Kentucky, Tennessee, West Virginia, Kansas and Minnesota.

It is probable that it spread from America to Europe and other parts of the world. It was reported from near Amiens, France, as early as 1872 (12:40), from southern France in 1877 (34:379) and from the neighborhood of Paris in 1879 (10:51). It is said by Frank (17:186) to have been found the same year in Germany near Leipzig, but Zillig (54:298) questions this since he finds the first official report of its occurrence in Germany in 1909. If it occurred in Germany during the intervening years it must have been very inconspicuous. Zillig (1923) states that in that country it sometimes causes a loss of 60 per cent of the crop. The first published record of smut in England was in 1919 (13:168) but there is evidence that it occurred in the British Isles as early as 1900 (52:443). Walker (49:15) reported it as common in Holland. It has also been reported from Denmark. The writers were also informed by Dr. Ito of the Sapporo Experiment station that it is not uncommon in Japan. The losses from smut in countries other than America have not usually been considered serious.

LOSSES FROM SMUT

Onion smut has caused—and is now causing—great losses to the onion growers because:

1. Many acres of land best suited for the growing of onions have had to be turned to the growing of other crops because the land was so impregnated with smut that a good crop of onions could no longer be grown.

2. It costs just as much to tend a crop where smut has reduced the stand as it does to tend a full stand but the returns are less. The diminished yield frequently leaves no margin between cost of production and the selling price.

3. The price of chemical, special apparatus and extra labor for application of chemical, where preventive measures are used, must be added to the production cost.

The Plant Disease Survey of the United States Department of Agriculture (32:210) estimated the loss from this disease in the United States in 1918 at 754,000 bushels. In individual fields in Massachusetts losses may vary from 0 to nearly 100 per cent.

At attempt to calculate the losses in dollars would be conditioned by so many modifying factors that it would necessarily be the merest guess and no such attempt will be made by the writers. It is, by all odds, the most important disease of onions occurring in America, and time or money spent in controlling it is well worth while.

SYMPTOMS

The first signs of smut appear on the young seedlings within two or three weeks after the seed are planted. In fact, the very first recognizable indication of disease has been observed here (1:131) within ten days from the date of planting. The cotyledon (or seed leaf) which is the first part to appear above the ground is marked by a slight distortion and swelling instead of being perfectly straight as is the case with a healthy plant. A few days later, when one holds the plant up to the light and looks through it, he sees a dense black, opaque, elongated area (or several of such) inside the seed leaf. Many of these weakened plants "damp off" and fall at this stage. Even if they do not damp off they gradually shrivel and die if the attack is severe. If one crushes these dead cotyledons he finds them filled with a black powder (spores). The heaviest loss in an infested field is during this cotyledon stage; the grower notices that his rows become thinner day by day, until only a fraction of the seedlings which came up remain standing. If, however, the initial attack was not very severe the plants do not die in the cotyledon stage but the successive leaves develop and in many cases are perfectly healthy, the disease having been sloughed off with the cotyledon. But usually smut will appear as long dark streaks in each of the succeeding leaves. Such plants remain stunted and the leaves are short, brittle, and distorted (Fig. 1A). They continue to die in various stages of development throughout the summer. Very few of them develop bulbs of any size. Even if they continue to live until time of harvesting, they are never stored because in the last stages they develop "bottom rot" and are thrown out. As the diseased plants grow larger, the black smut pustules (or lesions) also increase in size. They may be several inches long or extend throughout the entire length of the leaf. As the leaf becomes old and dried these lesions split open and the spores fall out (Fig. 1A). Frequently they rupture to the inside of the hollow leaf. On the bulb itself, the pustules are raised and appear gray as one looks at the black mass through the white covering of the scales (Fig. 1B). When the outer scales die the black spores fall out into the soil (Fig. 1). The appearance of a row of diseased onions as compared with a row of healthy onions is shown in Fig. 2.

THE CAUSE OF SMUT

Smut is produced by the growth inside the tissues of the onion of a parasitic fungus of the order Ustilaginales. The spores of this fungus were first distinguished and figured by Taylor in 1872 (43:193 and Fig. 29), but the first accurate description is by W. G. Farlow of Harvard University in 1876 (14:175). C. C. Frost of Brattleboro, Vt., had previously examined it and found that it belonged to the smut genus,

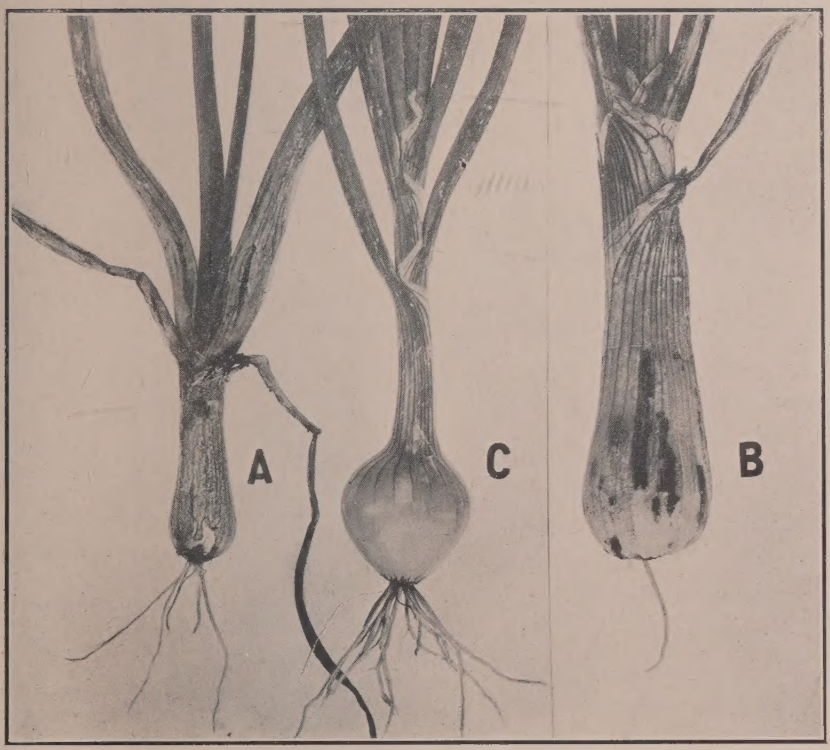

Fig 1.—Symptoms of smut on mature onions. A. Showing distorted leaves with ruptured pustules exposing black spore powder. B. Smut pustules on bulb. C. Healthy onion for comparison. Note failure of diseased plants to develop normal bulbs.

Fig. 2.—Formaldehyde treatment for smut. 2 rows in center received no formaldehyde.

Urocystis, and had sent some specimens to Farlow with the appended name *Urocystis cepulae* (*cepulae* means *of the little onion*). Farlow adopted Frost's name and published a description but indicated Frost as the author of the species (although the latter apparently never made a description). Some of the European writers (*e.g.* Cornu and Frank) quote Farlow as the author. It is usually referred to as *Urocystis cepulae* Frost.

Shortly after Farlow described this as a new species there was considerable discussion among students of fungi as to whether this really was a new species or whether it was identical with some previously described smut. No smut fungus had been described previously from the cultivated onions but some had been described from wild species of the same genus and from closely related genera of the Liliaceae. Thus *Urocystis magica* was described from Italy on *Allium magicum*. Farlow, in his second paper (15:114) expresses the opinion that *U. cepulae* is identical with *U. magica* Pass. Another closely related smut is *U. Colchici* Schlecht which occurs on *Allium rotundum* and a number of species of the Liliaceae outside the genus Allium. Farlow pointed out the differences between *U. Colchici* and *U. cepulae* and considered them as distinct. Cooke (9:634) however, considers the difference insufficient for specific rank and calls the onion fungus *U. Colchici var. cepulae*. Magnus (28:348) also considered *U. cepulae* as distinct from *U. Colchici*. Schroeter and Winter (Die Pilze, p. 121, 1884) would unite all the above species under *U. Colchici*. Magnus and Cornu agree with Farlow in keeping the two distinct. Clinton in his monograph of the North American Ustilagineae (8:451) says, "There has been some discussion whether the American species is distinct from *Urocystis Colchici* and *Urocystis magica* of Europe, the latter species also occurring on species of Allium. The three while very closely related are distinct. The species described here (*U. cepulae*) differs from both in having smaller spores and spore balls and also from *U. Colchici* by rarely having more than one spore in a ball." Another species of Urocystis on Allium is *U. Allii* (Belham) Schellenberg on *Allium subhirsutum*. The writers have not examined this species, but both Liro and Schellenburg regard it as distinct from *U. cepulae*. Inoculation experiments by Anderson showed *A. subhirsutum* to be one of the few species of Allium which are immune to *U. cepulae*.

Liro (27) has recently merged the genus Urocystis with the older genus Tuburcinia because he was unable to distinguish any morphological differences between them and has proposed the name *Tuburcinia cepulae* (Fr.) Liro as the correct name for the onion pathogene. This change has been adopted by European writers but as yet has not appeared in American literature. In both of these genera, the spore —more commonly called the "spore ball"—is not a single cell but is composed of a globose ball of a number of cells permanently bound together. In Tuburcinia all of these cells are fertile, *i.e.* capable of germination, while in Urocystis only the central ones are fertile while the peripheral ones are sterile and called accessory cells. In opposition to this usual conception Liro maintains that no such distinction exists, but that in all these species there is a covering layer of sterile cells. When Fries erected the genus Tuburcinia, the first species which he placed under it was *T. Orobanches*, the spore ball of which is composed of 1-3 larger central cells surrounded by a compact layer of smaller, flatter cells. Contrary to the opinion of most previous students of this genus, Liro considers the smaller outer cells as the sterile accessory cells and therefore, that this spore ball differs from that of ordinary species of Urocystis in no way. From examination of slides of Fries' original specimen kindly furnished by Dr. Liro, the writers were able to confirm Liro's conclusions in regard to the relative size of the cells; but it should be kept in mind that the separation of the genera is not based on differences in size of central and peripheral cells but on their ability to germinate. Microscopic examination of these slides did not disclose any difference in the outer cells which would prevent germination. Brefeld (Untersuch. A.D. Gesammtg. d. Myk. Heft. 12:180 and Pl. XI. 1895) has published excellent figures of the germination of the spores of *Tuburcinia primulicola*, a species very similar to *T. Orobanches*, and he shows the peripheral cells germinating in large numbers. He was unable to find any sterile cells outside of those which germinated. Liro does not mention any germination studies and there is no record in the literature that the germination of the spores of *T. Orobanches* has been observed. Until the germination of these spores has been studied, and until there is some concord of

opinion among mycologists as to the constancy of the sterile layer of covering cells, we prefer to retain for the onion smut organism the name which has been in continuous use for the last fifty years.

The true onion smut fungus *U. cepulae* Frost, does occur, however, on other species of Allium. Clinton (8:451) reported it on specimens of *A. Nevadense* from Nevada. In England the disease is said to be more severe on leeks (*A. Porrum*) than on onions (13:170) and was reported from France on this host as early as 1881 (29:277). Quite recently (55:57) Zillig has reported that he was able to infect *A. fistulosum* L., *A. globosum* Red., *A. odorum* L. and *A. Porrum* L.

One of the writers, before he was aware that Zillig was working on the same problem in Germany, began a series of inoculations by planting seed of all obtainable species in soil which was very heavily infested with *U. cepulae*. Records taken every week after the plants came up gave the total percentage and severity of smut infection for each species. A full description of these experiments and the results are published elsewhere (4). Briefly, it was found that out of 39 species which were tested, 8 proved to be immune to smut, while 31 showed varying degrees of susceptibility. Thirteen species were just as susceptible as the common onion in that the disease affected them in just the same way throughout the season. In five others it caused heavy mortality in the cotyledon stage but did not persist throughout the season. In 13 others the cotyledons were sometimes affected, but the plants rarely if ever died from the effects of smut. These results lead us to believe that if the numerous other species—there are some 250 species in the genus—were tested in the same way, a large proportion of those which reproduce by seeds would be found to be susceptible. (Many species escape the disease by reproducing only by bulblets.)

Within the species *Allium Cepa*, the cultivated onion, there are numerous varieties, but up to the present there are no data or observations to indicate that any of them show any degree of resistance to smut. It has been stated at various times, however, that the white varieties are somewhat more susceptible than the red or yellow ones. Walker and Jones (50:236) tested several varieties, and Whitehead (52:449) tested 21 varieties of onions and 11 varieties of leeks (*A. Porrum*) but none was found which showed resistance. Anderson (4) tested 54 varieties of cultivated onions but found no significant indication of resistance among them.

*Morphology and Life-History of the Smut Fungus**

If one examines microscopically the dusty black mass from the leaves or bulbs, mentioned above, he will find that each particle of dust is a spore (chlamydospore) of the fungus which causes smut. It is a compound spore composed of one large central brown cell, to the surface of which are attached 15–40 smaller hemispherical cells (see Fig. 3A). The dark central cell is the fertile cell, while the numerous smaller surrounding cells, which are transparent, but with a brownish tint, are the sterile cells (pseudospores or accessory cells).

The spores get into the soil either by the rupturing of the sorus (pustule) or by decay of the infected part of the onion which has fallen to the ground. In the soil they may germinate at once or after a few weeks or months, or they may remain for years before germination occurs. In either case they grow into long slender branching tubes (the mycelium) and in a favorable soil this growth may be sustained for many years even though onions are not planted again on the same field. The mycelium does not produce other spores (*sporidia* or *conidia*) but it may break up into short pieces which are able to lie dormant for long periods and then germinate on the return of favorable conditions. The soil becomes so infested with spores, mycelium and these detached mycelial segments that without preventive measures onions can no longer be raised on it.

Method of germination of the spores. In a previous publication Anderson (1:108) has described the process of germination as it occurs during the first few months after maturity of the spores. Briefly it is this: A globose hyaline body, at first no larger than one of the sterile cells but later becoming as large as the fertile cell, develops on the surface of the fertile cell (Fig. 3B). From this body one to eight germ tubes grow out (Fig.

*In a previous publication from this station (1) the reader will find more detailed information on the full life history of *Urocystis cepulae*. In the present publication the seasonal life-cycle is outlined very briefly.

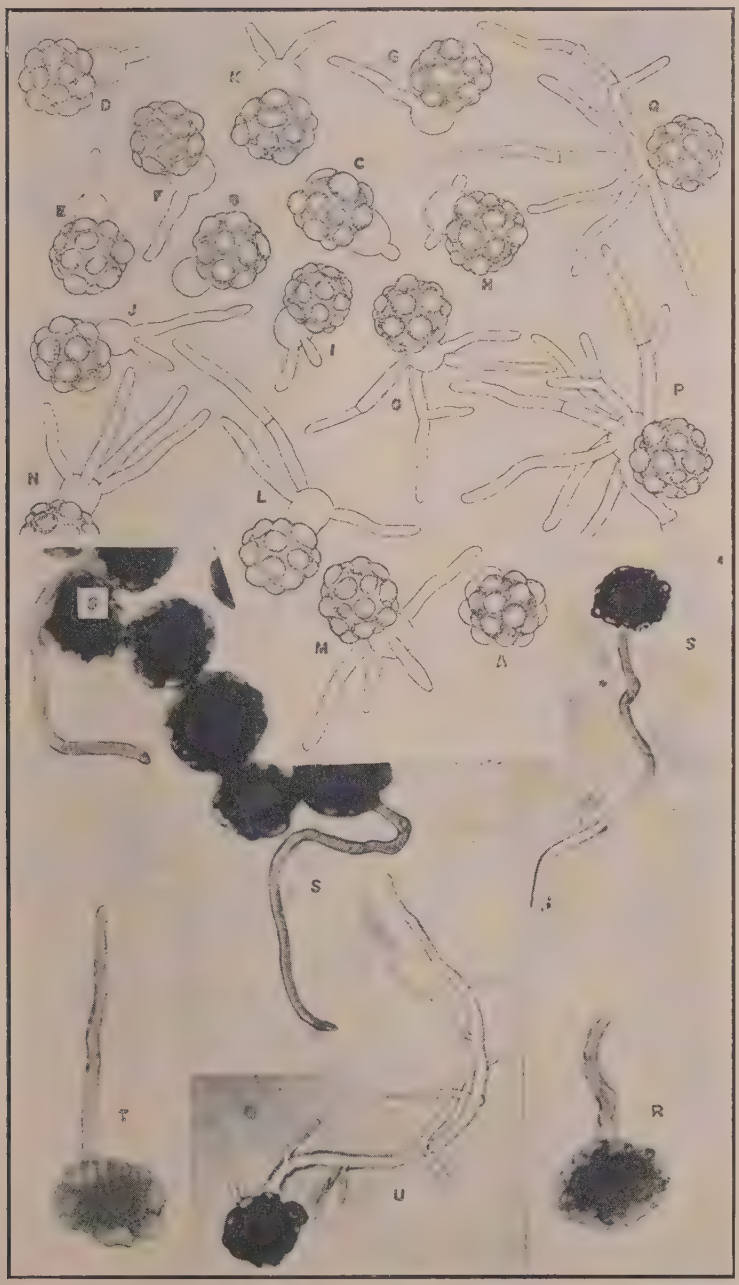

Fig. 3. Germination of onion smut spores. A. A fresh spore before germination. B-Q. Successively older stages of germination of spores three months after maturity. Camera lucida drawings. R-U. Successive stages in the germination of spores after ripened in soil for three years. Photomicrographs.

3C-Q) and by elongation, branching and septation form a dense mycelium without any indication of sporidia. Subsequent to the publication of these results, smutted leaves were placed in damp soil in test tubes where they were kept for three years. At the expiration of that time the spores were again tested for germination by the same method as was used in the previously reported tests. The process of germination was now found to be quite different from that which took place during the first three months after maturity. Most of the sterile cells had now collapsed and no longer presented the plump appearance which they have on fresh spores. Germination began within 2-5 days after the spores were sowed on the cold agar plates. The first striking difference was that there was no large globose body developed on the face of the fertile cell, but a single slender tube grew out directly from the central cell (Fig. 3R-U). Occasionally two tubes seemed to come from the same place, but the second one may have been merely a branch of the first arising very close to the surface of the spore. Usually the germ tube remained simple and unbranched until it had reached a length of 20–30 times the diameter of the spore. Then it became septate and branched sparingly. The protoplasm disappeared from the older cells but remained dense in the advancing tip cells. No sporidia were observed at any time even when the further development was examined daily until masses of mycelium a half-inch or more in diameter were formed. All the further development and behavior of the mycelium was the same as previously described after the germination of the spores according to the first process. The process of germination of these "after-ripened" spores is very similar to that described by Thaxter (44:142) and Whitehead (53) except that both of them found sporidia. The difference in germination between fresh spores and after-ripened spores is susceptible of various interpretations, but none will be attempted until after further investigations have been made.

It is commonly stated in the literature on onion smut that the chlamydospores live for many years—any number up to 25 may be found—in the soil and then germinate to infect the seedlings when onions are again planted. Such statements are erroneously based on the observation that smut recurs on a certain piece of land which has not been planted to onions for that particular number of years. It seems more probable that the smut is carried through those years in the form of mycelium living on the organic matter in the soil. Another possibility is that the spores or other organs of the fungus may have been washed or carried in some other way from fields where onions had been grown in the interim. During the season of 1923 smut occurred in destructive form on a plot of land on the experiment station farm which, as the records showed, had not been planted to onions in at least 40 years, but this plot was adjacent to another field where onions had been grown during many years. A similar case is reported by Whitehead (52:444). There are numerous ways in which it could be spread from one field to another, *e.g.*, by surface washing, wind, tools, animals, direct spread of the mycelium, workmen, etc.

From the soil the mycelium enters the very young seedlings by boring directly through the epidermis. Infection may occur only during a very limited period while the epidermis is tender. The exact length of this period was determined by Walker and Jones (50:238) and by Anderson (1:120). Walker and Jones found that "the plants became immune . . . between the nineteenth and twenty-fourth days after sowing, when the cotyledon had about attained its full growth and as the first leaf was emerging." Anderson found that they were no longer susceptible after the 17th day under greenhouse conditions, but that "the period of susceptibility is not limited by the number of days during which the seeds have been in the soil, but by the length of time required for the seedling to pass through certain stages of development" and that "susceptibility begins to diminish from the time that the knees emerge from the ground and little if any infection occurs after the first leaf has emerged from the side of the cotyledon." Thus the conclusions from these two investigations -carried out at the same time, but entirely independently, were identical—that all infection occurs before the first leaf is developed—a period which may be roughly stated as 3 weeks after planting. Walker and Jones very ingeniously demonstrated that immunity after this period depends on the maturity of the tissues of the cotyledon or the successively developed leaves each of which in turn forms a protective sheath about the base of the next developing leaf.

As soon as the infecting mycelium has passed through the epidermis of the cotyledon, it spreads rapidly in all directions, deriving its food from the cells of the young onion. After growing for a period of 5–10 days the mycelium forms dense knarls between the cells of the host plant and then the knarls are transformed into masses of black spores which have been previously described. It must not be

understood, however, that the mycelium from a single point of infection grows throughout the whole length of the cotyledon. On the contrary, a single mycelium probably never extends more than a quarter of an inch from the point of infection and the ripe sorus is developed at that point. If there are a number of sori in the cotyledon—which is usually the case—they are the result of the same number of separate infections. Very long sori in the cotyledon are the result of anastomosing shorter sori.

Just at the junction of the young cotyledon and the first root there is a slight swelling known as the root joint. Immediately above this is the growing point,—a region of less than a half inch,—from which place all new leaves start. This point remains stationary throughout the further development of the onion bulb. If an infection occurs near the growing point the mycelium reaches this rapidly dividing tissue and as each leaf grows up it carries with it some of the infecting mycelium which spreads and sporulates in the leaves. When an onion once becomes infected in the growing point, it never recovers. If, however, the cotyledon is infected only in the upper part the mycelium does not reach the growing tissues and the disease is sloughed off with the cotyledon and the plant develops normally.

RELATION TO ENVIRONMENTAL FACTORS

Most plant diseases vary greatly in prevalence and severity according to the season. Certain kinds of weather favor them, others retard them. They ruin the crop one year and are entirely absent during other years. Onion smut, however, differs from most common diseases in this respect: It is about the same every year. Some growers think they find it more severe during a dry year; just as many others think a wet year favors it. The writers have had occasion to watch the course of the disease for many years but have never noticed any marked difference in its severity from year to year on the same field. Walker and Jones (50:240) conducted controlled experiments in the greenhouse to determine the effect of variation in the moisture of the soil on the percentage of smut infection and concluded "that soil moisture does not function as a factor limiting infection with onion smut within the limits at either extreme where good germination and growth of the host occur."

A similar experiment was conducted by the writers at the Massachusetts Experiment Station in which the seedlings were grown in pots of naturally infested soil kept at moisture contents at intervals of 2 per cent. from 12 to 40 per cent. of the dry weight of the soil. Below 12 per cent. this soil was too dry for good germination, while at the upper limit it began to decline rapidly from 34 per cent. Within this range the smut loss was almost total. Above 34 per cent. there was a decline in the percentage of infection, but the soil was very muddy and it is not likely that any grower would plant onion seed in soil so wet as this. It is conceivable, however, that rains immediately following the planting might keep the ground so wet that infection would be reduced, but probably the loss of germination on account of wet soil would more than counterbalance the gain from decreased infection. The practically identical results of these two experiments conducted independently in Wisconsin and Massachusetts indicate that the moisture condition of the soil in the spring is without influence on prevalence of the disease during that year.

Neither is there any indication that a warm spring in the Connecticut Valley is any more or less favorable than a cold one. All the onions here are planted in the early spring before the soil becomes very warm. Walker and Jones (50:247) conducted experiments on the effect of soil temperature on infection and concluded "that a high percentage of infection may be expected up to 25° C. (=77° F.) above which there is a rather abrupt reduction, leading to complete inhibition at 29° C. (=84° F.). There appears to be no lower limit of temperature for infection within the range where onion seeds will germinate and normal growth occur." They explain the absence of smut from the southern onion regions, *e.g.*, Texas and Louisiana, as due to the fact that in those regions the seed is planted in late summer when the soil temperature is too high for infection to occur.

The temperature experiments of Walker and Jones were also duplicated at the Massachusetts Experiment Station and the results were practically the same. Onion seed germinated at all temperatures between 8° and 35°C., but the percentage

drops off rapidly above 27° and is much retarded below 13°. It required 33 days for the plants at 8° to show above the surface of the soil. The optimum is between 15° and 27°. Smut was not entirely absent at any temperature tried, but the percentage dropped off suddenly and rapidly above 27°. Below 27° there were no significant differences at any temperature. There seems to be no lower limit of infection within the range of germination of the onion seeds. This suggests the possibility that smut might be avoided or diminished by delaying the planting here until the soil became warm. Late planting, however, is not conducive to good crops in the Connecticut Valley and, in addition, this method has been tried (50:237) here without any beneficial effect.

It is apparent from the results of the experiments just mentioned that the only soil temperatures which could influence prevalence of smut would be from 27°C. (81°F.) upward. Does the soil of the Connecticut Valley onion region ever approach such high temperatures during the infection period, *i.e.*, approximately during April and May? We have no local continuous seasonal records for the soil, but since all infection occurs within the upper inch of soil we may approximate it from the air temperature records during those months. The soil temperature during the heat of the day, to be sure, may rise several degrees above that of the air, but we may allow a latitude of ten degrees or more and still reach some conclusion. Weather records at Amherst for the ten-year period 1915–24 show the mean hourly temperature for the month of April to be 45.8°F. and for May, 56.5°F. Even though the soil temperature in parts of the field were 20° higher than that of the air —which is beyond reasonable limits for any length of time—it would still not be high enough to limit infection. As far as Massachusetts is concerned then, soil temperature seems to be as unimportant as soil moisture.

We may conclude, therefore, that variations in weather conditions are without effect on the severity of smut infection. There is, on the contrary, very good evidence that certain soil factors may have a deciding influence. A survey of the Connecticut Valley region shows that fields are very unevenly infested. Onions always suffer most in certain fields. In the same field, certain spots are very heavily infested while other parts of the field suffer little. The location of these spots remains approximately the same year after year although the whole field is planted to onions each year and the treatment of all is the same. Such a condition cannot result from any lack of opportunity for the fungus to spread. It can apparently mean only that there is some soil factor which is right for the growth of or infection by the fungus in that part and not in the other parts of the field. Investigation with the object of determining this factor (or factors) is now in progress at this station, but it has not progressed to the point where any conclusions can be drawn.

PREVENTION OF SMUT

When the ravages of smut first began to attract attention of New England onion growers (1850–75), it was thought to be connected in some way with the character of manures applied to the soil, guano being held especially responsible. Remedies were therefore sought through change of fertilizers. Thus Horace Capron (7:224) suggests: "A remedy for this disease must be sought by using less manure, or manures which are less stimulating and afford less nitrogen for the fungus to feed upon. Alkaline manures are very destructive to the fungus. Wood ashes, lime, gypsum and seaweed are very efficacious."

Taylor (43:195), who first made a study of the spores and laid stress on their presence in the soil as a means of carrying the disease over winter and spreading it about, recommended that they be destroyed and the disease thus controlled, by burning heaps of dry weeds and rubbish on the infested fields. This recommendation was repeated by various writers during the next fifteen years, but it does not appear from the literature that anybody tried it. Walker (47:6) has recently recommended burning the onion tops after harvest and the avoidance of returning onion refuse to the soil.

Farlow (14:174) was the first to suggest rotation of crops as a means of control. He was led to believe from the statements of growers that the spores do not live in the soil more than four years and thought that if a smut-infested field were planted

to other crops for four years, it would then raise a smut-free crop of onions. He did not think that the spores were carried by wind and in order to prevent the carrying of spores to uninfested fields, he recommended thorough cleaning of all tools which had been used on smut-infested land. Thaxter (44:138) on the other hand, finds that a badly infested crop of onions was grown on a field which had not been planted to onions for twelve years. Sirrine and Stewart (37:149) find in regard to the value of crop rotation: "it is the common experience of onion growers that even an occasional change of the crops for one or two years gives appreciable relief; and it is our belief that a systematic rotation of crops would very considerably reduce the amount of loss from smut." Farlow was also the first to recommend that all smutted onions be pulled during the growing season while the crop is being weeded, and that they be removed from the field and burned. It is not recorded in literature that this method was tried by any grower.

The first accurate experiments of any value on control are those of Thaxter (44:146) who was at that time mycologist of the Connecticut Agricultural Experiment Station. He applied various dry chemicals to the soil in the drills to see whether any of them would prevent infection of the seedlings by the fungus. The chemicals used were copper sulfate, iron sulfate, sodium sulfide, potassium sulfide, potassium chloride, calcium chloride, sodium hyposulfite and flowers of sulfur. Air slaked lime was tried also in combination with some of them. The mixture of air slaked lime and flowers of sulfur gave a fair percentage of control. The others injured the germinating seeds, or were of little or no value in preventing smut, or their use was impracticable. He repeated the experiments the following year (45:103) and again was able to increase by a ratio of about 5:1 the number of onions which could be raised on badly infested land, by the use of flowers of sulfur. Thaxter, himself, however, was not very enthusiastic in his recommendation of the method and two years later his successor, Sturgis (41:14) writes concerning it: "It seems probable now that the measure of success attending this treatment will hardly warrant its extended adoption."

The sulfur-lime treatment was thoroughly tested by Sirrine and Stewart (37:152), their field experiments extending over a period of five years. As a result of all their experiments they conclude (37:145) "that the yield of onions on smutty land may be greatly increased by the application of 100 pounds of sulphur and 50 pounds of air-slaked lime per acre in the drills at the time of sowing the seed. In several instances the yield has been increased at the rate of more than 15,000 pounds per acre as compared with untreated plats. Sulphur alone has considerable value as a preventive of smut, but seems more efficient when mixed with lime. The sulphur and lime should not be applied broadcast as they appear to have no effect on the smut when applied in that way. The sulphur-lime treatment is recommended whenever the loss from smut is as much as one-third of the crop."

Thaxter (44:146) found that infection occurred only in the very young seedling stage. Thus, when the plants were started in sterile soil and then transplanted to the field, they never suffered from smut. Sturgis (42:176) made extensive field tests of this method and demonstrated that it was an absolute preventive of smut. It was also recommended by Sirrine and Stewart (37:145). This most effective of all methods of control has not been adopted by onion growers in general because the amount of labor and time required for transplanting is so great as to render it impracticable where onions are grown on a large scale.

Burying of the surface soil has been tried with some success, but the labor involved is excessive (37:149).

The use of larger quantities of seed on smut infested land has been tried (37:149) but as pointed out by Sirrine and Stewart "there comes a time when it is impossible to obtain a stand no matter how much seed is used." Such a method is also impractical on a field which is unevenly infested, because the onions are too thick on lightly infested parts of the field and laborious thinning is necessitated.

In 1900 Selby (35:76) began experiments in Ohio, using the lime and sulfur treatment as recommended by Thaxter, various other chemicals, quick lime and formaldehyde. After the first year's experiments (1900) he abandoned all but the formaldehyde and the quick lime since they alone gave promising results. All the experiments were on seed sowed very thickly (about 40 pounds per acre) for the production of sets. During the second year he used only the quick lime and the

formaldehyde or a combination of the two and obtained a considerable degree of control. In regard to his method of application we quote from his summary (50:51).

"To apply formalin, use at rate of one pound commercial formalin in 25–30 gallons of water (1 oz. to 1½–2 gals.) and apply with drip attachment on seed drill at rate of 500–700 gallons of solution per acre for onion set seeding (about ⅛–¼ as much for field onions) or apply with sprinkler upon the scattered seeds until well moistened, then cover with earth promptly.

"Apply ground quick lime or stone lime, better the former, at the rate of 75 to 125 bushels per acre just before seeding, on the freshly prepared soil. If applied by drill, harrowing will not be required; if broadcast, harrowing should precede planting."

Stone (39) recommended formaldehyde at the rate of 1 lb. to 30 gals. (1–240) or 1 oz. to a gal. of water (1–128*). With the improved tank which he describes in detail he found that about 1200 ft. of drill could be treated with one gallon of the solution.

Within recent years all other methods except the application of formaldehyde have been abandoned, since this has given good results and is the most convenient. Various concentrations of the solution and quantities per acre or given length of row have been recommended. The most recent and thorough investigations have been those in Wisconsin by Walker (37). After experiments of several years' duration he recommends the use of formaldehyde at a dilution of 1–128, applied at the rate of 200 gallons per acre, or one gallon to about 185 feet of drill (1–128–2160, or approximately equal to our 1–128–3000 formula).

In England, Whitehead (52:44) recently made control experiments in which he treated the seed with various percentages of sulfuric acid and with permanganate, other experiments in which the soil was treated with soot and soil, paraform, bleaching powder, lime, nitrate of soda, sulfur and lime, calcium cyanamide, carbon bisulfide and formaldehyde. In the summary of the work he recommends only formaldehyde.

We may briefly summarize the methods of control which have been recommended in the past and their present status:

1. Modification of the fertilization of the land has been of no avail. We do not believe, however, that the possibilities of this field of investigation have been exhausted.

2. Removal or destruction of diseased onions or refuse is wasted time.

3. Rotation of crops is of little, if any, value because of the length of time during which the fungus lives in the soil and because of the facility with which it may be introduced from neighboring fields. It is also not economically practicable on high-priced onion land.

4. Search for resistant varieties has yielded nothing up to the present, but should be continued.

5. Burying the surface soil is too expensive to merit consideration.

6. Sterilization of the entire field by heat or chemicals is also too expensive.

7. The use of larger quantities of seed is ineffective.

8. The use of transplanted seedlings is an absolute preventive, but such a method of culture is considered too laborious by growers of the Connecticut Valley region.

9. The use of sets is just as sure a preventive. This is being practiced more extensively every year, not only because of the smut situation but also because of less damage from thrips and of larger yields. The early harvesting of the crop, however, has distinct disadvantages from the storing and marketing standpoint.

10. Chemicals other than formaldehyde have proved worthless, injurious, or at best, very much inferior to that chemical. Sulfur and lime have given the most promise, but are no longer used.

11. The use of formaldehyde is the only treatment which is now recommended or extensively used. The principal objections to the formaldehyde method are—

(1) the use of large quantities of water which greatly increases the labor at planting time, and

(2) danger of injury to the seed.

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*Walker also tried (38:278) the sulphur and lime method described by Sirrine and Stewart but found it inferior to the formaldehyde method "both as to efficiency in controlling the disease and ease of proper application."

It was with the object of reducing these difficulties to the practical minimum that field experiments were undertaken by this station. The problem was to find a formula of application* in which the water should be reduced to the lowest possible amount, but without serious damage to the germinating seeds.

The Cowls Farm Experiment, 1919

This experiment was located on a field so heavily infested with smut that the loss was almost complete during the preceding year. Three formulas were used, 1–64–3200, 1–96–3200 and 1–128–3200. The rows were 150 feet long, two untreated rows alternating with each plot of four treated rows and the whole series in triplicate, thus giving a total of 1800 feet of row treated according to each formula. Plots were planted on April 22. The soil was fairly moist when planted; there was only a slight precipitation during the next week, but the month of May was very rainy. No difference between the rows was apparent when they first came up but within a short time the treated rows looked greener and were thicker because of the dying of the smutted plants in the untreated rows. This dwindling continued throughout the summer as more of the smutted onions died and disappeared. On June 2, the number of onions in measured lengths of the rows was counted. Also the percentage of smut among those standing was determined. From an inspection of these data (Table I) it is apparent that there had been a large shrinkage from smut before that date and that half, at least, of those still standing in the untreated rows were smutted. Smut was not eliminated from the treated rows but it was so reduced in amount that the rows were too thick for the growing of bulbs of good size. During August thrips did serious injury, causing the tops to die prematurely. The bulbs on the check rows were much larger than on the treated rows because, after most of the seedlings died, they were far apart and had thus opportunity to grow larger Very few of the diseased onions were still standing at harvest time and most of them were rotted at the base. Only rarely did one attain a diameter of one inch. The number of sound bulbs in each row was counted as they were pulled. After they had dried for a few days, each plot was also weighed separately. The data is summarized in Table I (p. 27). The comparative yields of treated and untreated rows are also shown in Fig. 4. The difference between the results secured by any of the three formulas is not large. Any of the three shows a gain of over 250 bags (100 lbs. in a bag) per acre. The control secured by the use of any one of the formulas was satisfactory.

If one prefers to measure the efficiency of the treatment by the gain in pounds, the 1–96 formula was somewhat the best. If, however, he wishes to consider the *number* of healthy onions at harvest time as the basis of comparison, the 1–128 formula is somewhat better.†

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*Formaldehyde (*i.e.* the 32–40 per cent. solution of the gas in water) cannot be applied in the concentrated form to the seeds in the row because even a very small quantity prevents the seeds from germinating. It is therefore necessary to dilute it with water. The first question to be answered then is: how much should it be diluted? This is the first variable in the experiments but this variable depends in turn on a second variable viz. the rate at which the diluted solution is to be applied to the row. For example, a 1–50 dilution is excellent if a gallon of it is applied to 700 feet of row but disastrous when applied to 200 feet and worthless when applied to 1400 feet. The numerical expression of these two variables is called the "formula of application." For all of our experiments it is written in terms of pints of formaldehyde—pints of water—feet of onion row. To illustrate: the formula 1–50–3000 means one pint of formaldehyde is diluted to 50 pints with water and the 50 pints of diluted solution applied to 3000 feet of onion row. Thus the first and second figures express the rate of dilution while the second and third figures express the rate of application of the diluted solution to the row in terms of pints of solution and feet of row. In the literature on onion smut control the rate of application is commonly expressed as so many gallons per acre of onions. This is undesirable because we do not treat acres but rows, *i.e.*, the amount of solution should be proportionate to the number of feet of row and not to the area of the field. The number of feet of row in an acre varies according to the distance between the rows. Different growers plant the rows at different intervals. Even in the restricted area of the Connecticut Valley one may find fields of onions planted at 12, 13, 14 or 15 inches and none of them is uncommon. In other sections of the country under different methods of culture other intervals are used. In order that results obtained at one place may be compared with those from another, it is desirable that formulas be expressed according to length of row treated and not acres. It should also be kept in mind that a direct comparison cannot be made between the results of the use of two formulas in which both variables are fluctuating at the same time: One must remain constant while the other is being changed.

†*Methods of calculating the results*: The writers have given considerable thought and attention to the question of the most accurate method of calculating and comparing the results obtained by the use of the different formulas of application. The methods which we have tried—most of which are in use by other investigators—are:

1. By counting the number of smutted seedlings when they are *in the cotyledon stage*. This method is

Fig. 4.—Formaldehyde treatment for smut. Yield from 4 treated rows (A), compared with 4 untreated rows (B).

Station Farm Experiment, 1919

The experiment on the Cowls farm was duplicated as regards treatments, but on a smaller scale, on a badly infested plot on the Station farm.

The check rows gradually dwindled throughout the summer while the stand on the treated rows remained excellent. No differences between the results obtained by the use of any of the three formulas could be observed. Through a mistake, the onions of this plot were harvested in the absence of the writers and final data on yield were not obtained. Unquestionably, however, they would have paralleled the yield data for the Cowls farm.

Greenhouse Experiments, 1919–20

During the winter a greenhouse bench 4 x 16 feet was filled with soil from a badly infested field. Three crops of onions, raised in succession, were treated with formaldehyde of different formulas. Commercial formaldehyde was applied at the rate of one pint to 2400, 2800, 3000 and 3200 feet of row. Dilutions from 1–8 up to 1–128 were used. Without presenting all the data, we may state the tentative conclusions at which we arrived as a basis for the field experiments of the following year:

1. The percentage of control was not appreciably greater when one pint of commercial formaldehyde was applied to 2400 or 2800 feet of row than when applied to 3000 or 3200 feet.
2. Concentrated formulas such as 1–48–2400, 1–32–2800 and stronger cause serious injury and cannot be used.
3. The most important indication of the series was that within wide limits, the amount of dilution is not a factor of any great importance *as far as control of smut is concerned.*

C. A. Clark Farm Experiment, 1920

This experiment was on land in Sunderland where onions had been grown for 40 or 50 years. The soil, however, was not as thoroughly infested as that on the Cowls farm used during the previous season. The part selected for experiment included 30 rows, 267 feet long, 12 inches apart, seeded at the rate of 7 pounds per acre. The plots were seeded May 3, the soil at that time being wet and heavy after a backward

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inaccurate because it makes no distinction between those which are badly affected and will die and those which are slightly affected and may produce good onions. Also we have found that it is impossible to distinguish all the diseased plants because many of the lesions are below the surface of the soil.

2. By counting the percentage of smutted plants among those which are standing at some definite period *in the early summer, but after the cotyledon stage.* This was done in the Cowls farm experiment just described and is commonly used by other workers on onion smut. This method is worthless because it does not count those which have already died from the disease and disappeared. We have repeatedly noted that seedlings begin to die within three weeks after planting and the mortality is then heavy for a few weeks. When a young plant dies it shrivels and decomposes so quickly that no trace of it can be found after a very few days. Obviously such plants cannot be taken into consideration in calculating by this method

3. By removing and counting the plants *as fast as they succumb to smut.* This requires a thorough inspection about twice a week for a period of some four weeks, after which all diseased plants may be pulled since it is certain that they will not recover. This is certainly the most accurate method, but under field conditions involves so much labor that it is precluded. We have, however, used it in greenhouse experiments with satisfaction.

4. By counting and comparing the number of *healthy* bulbs in the row at harvest time or shortly before. This does not assume that all onions which have disappeared from the rows during the summer have succumbed to smut, but that all other agencies which would destroy the plants previous to this time would operate equally on all the rows. Therefore, the benefit derived by the grower can be determined by direct comparison of the figures thus obtained. From the experimenter's standpoint it is not quite satisfactory because it does not take into consideration the number of plants which were prevented from germinating on account of the use of formaldehyde of a certain formula. In the experiments of the last season we have determined the amount of such injury by comparing the number of plants which came up and then computing the control on the basis of those which remain. This fourth method has been used throughout the experiments here as being the most nearly accurate practical method of comparing the results obtained by a given treatment.

5 By comparing the *yield of onions in pounds or bushels.* This method is inaccurate because, as every onion grower has observed, the onions in a thin row (such as they are when thinned by smut) being further apart, are larger than in a thick row; therefore, bulb for bulb, are heavier. This difference, however, represents the gain in weight secured by growing bulbs further apart, and in no case could be interpreted as having any relation to the application of formaldehyde. If larger bulbs are desired, the result could be much more economically obtained by planting a smaller quantity of seed per acre while using the formaldehyde. This fifth method was used by the writers during the field experiments of 1919 and 1920 and the final weights are included in the tables, but they should not be considered as accurately gauging the results of the experiments.

spring. Also it rained within 24 hours after the seed was planted and the entire season was rainy.

The formulas used in this experiment require a few words of explanation. Since there was considerable smut in the treated rows during 1919 it was thought best to cut down the distance treated with one pint of the commercial formaldehyde from 3200 to 3000 feet. This also had the advantage of being approximately the same rate of application as was being used in the other states; therefore, our results could be more readily compared. The formulas 1–48–3000 and 1–32–3000 were added to see whether a more concentrated solution would give better control without injury under field conditions. In order to test the effect of increasing the length of row treated with one pint of commercial formaldehyde, the formulas 1–50–4000 and 1–50–5000 were added. From the standpoint of the growers, the 1–50 dilution is the most convenient because most of them use 50 gallon barrels for drawing the water and they all have gallon jugs or cans. It is, therefore, a simple matter to add a gallon of the commercial solution to each barrel of water.

Observations on the course of the disease throughout the summer coincided with those of the previous season. The percentage of smutted plants was not counted during the growing season for reasons previously stated. All the onions were pulled and counted on September 4. A week later they were topped and weighed. The data taken are recorded in Table II (p. 27).

In interpreting the results of this experiment the fact that the soil was very wet at the time of planting must be taken into consideration. The important influence which this factor exerted was understood only after the experiments of later years. We may draw the following conclusions from the data presented in Table II:

1. The highest percentage of control was secured by the use of the concentrated solutions: thus, the 1–64–3000 was the best*, but not much better than 1–32–3000 and 1–96–3000.

2. No advantage was gained by the extreme dilution and use of the large amount of water required for the 1–128–3000 formula. Three of the other formulas gave better control and others were not much inferior.

3. The decided drop in the percentage of control secured by the 1–50–5000 formula indicates that (during a wet spring) the amount of formaldehyde was insufficient. It resulted in a fair amount of control—40 per cent. increase over the untreated plots—but much below the benefit secured by the use of more formaldehyde per acre. The 1–50–4000 formula gave good control, but the yield was not quite so high as for some of the others.

The poor showing made by the 1–48–3000 formula is unexplainable in view of the good showing of the formulas just above and just below it.

The Kuzmeski Farm Experiment, 1920

The field on which this experiment was located is in Leverett and was seriously infested only in spots. The seed was planted May 3, the soil moisture conditions being about the same as previously noted for the Clark farm. Only two formulas were used, viz., the 1–96–3000 formula which approximated the formula which gave the best control during the preceding season, and the 1–50–5000 formula previously mentioned in the account of the C. A. Clark farm experiment. Eight rows, each 436 feet long, 13 inches apart, were treated with each formula, and four rows were left untreated as a check. Data for this experiment are recorded in Table III (p. 27).

The results shown in the table confirm the conclusion from the Clark farm experiment that the use of one pint of formaldehyde to 5000 feet of drill is insufficient for the control of smut during a wet spring. Entirely satisfactory control was obtained by the use of the 1–96–3000 formula.

C. A. Clark Farm Experiment, 1921

The experiment of 1920 on this field was practically duplicated during the season of 1921 but with the addition of some more concentrated formulas. The soil, how-

*In this connection, it may be noted that Walker (48:324) during two years out of his four years' experiments secured his highest yields by the use of the 1–64 dilution, while during the third year, it was only a close second to the 1–128 dilution that the difference was almost negligible. Despite these results, he recommended the 1–128 dilution.

ever, was dry and there was no rain for at least two days after the seed was sowed on April 13. The weather continued cold and the seed came up very poorly. When it did come up there was a striking difference between the treated and untreated rows. The checks were much thicker and appeared so throughout the season. There was a very obvious injury from the formaldehyde, irrespective of the formula used. The writers were informed by onion growers who were in a position to know the facts of the case, that growers all through the section had the same trouble with formaldehyde during 1921 and that many fields of onions were plowed under because of the reduced stand.

No yield data were taken in 1921 because the onions were harvested by mistake in the absence of the writers and no records were kept.

After the experience of 1921 it was decided that further progress in the search for the best formula could not be made until the factors which cause formaldehyde to injure were determined. The investigation of this problem was not finished until 1922, but since it has an important bearing on the subsequent experiments, we shall consider the findings at this time.

Formaldehyde Injury

At first it was thought that the injury of 1921 was due to some difference in the composition of the chemical. Samples from all available sources were therefore collected, including among them samples of the same material which we had used during the previous years and which had not caused injury. Chemical analyses of the samples by Dr. Holland of the Chemistry department, revealed no differences in composition which were of sufficient size or character to warrant a suspicion of their toxic effect. The manufacturers assured us that there had been no change in the method of manufacture of formaldehyde. The most apparent difference was in the percentage of methyl alcohol contained in the various samples. The sixteen samples were next tested simultaneously on onion seed sowed in greenhouse benches, using for each the formulas 1–50–5000, 1–50–3000, 1–100–3000 and leaving untreated rows between the plots. In order to see what effect variation in the percentage of methyl alcohol would have, samples containing known percentages from 0.4 per cent. to 16 per cent. alcohol were included in the tests. Without discussing the results in detail, they may be briefly stated as follows:—

1. The source of the formaldehyde was without influence on the percentage of plants which came up.
2. Variation in the percentage of methyl alcohol made no difference.
3. With all samples and every formula used, formaldehyde *retarded* germination for a day or two and
4. With all samples and formulas, formaldehyde *prevented* the germination of a certain percentage of the seed, this loss being more apparent when a more concentrated solution was used or where the quantity of the solution was increased.

The results of these experiments eliminated the possibility that the losses of 1921 were referable to difference in the character of the formaldehyde.

Since there had been no differences in the formulas or method of application of formaldehyde nor in the treatment of the soil in 1921, there appeared to remain only the character of the season itself as a possible explanation of the trouble. The character of the spring weather could obviously affect the soil—where the injury occurs—in two ways: (1) in the percentage of moisture and (2) in the temperature. Experiments were undertaken with the object of determining to what extent the percentage of injury is influenced by variation in the percentage of moisture in the soil. The effect of the soil temperature on injury has not been determined as yet.

These experiments have been described in detail in a previous publication (2). For our present purpose it will be sufficient to quote from the summary of that paper:

"When a concentrated formula like 1–50–3000 is used, the amount of injury depends on the moisture condition of the soil. Injury varies inversely as the percentage of moisture.

The amount of injury may be reduced by diminishing the amount of the solution applied per unit of row, but the percentage of smut control is probably also reduced.

The amount of injury in a dry soil may be reduced by increasing the dilution of

the formaldehyde without at the same time reducing the actual amount of formaldehyde per unit of row.

The amount of injury can be predicted from the moisture condition of the soil on the day of planting. It is not affected by weather conditions during the subsequent days.

The grower could save time and labor by changing his formula according to the soil condition at the time of planting.

More seed should be applied when formaldehyde is used."

The final results of the formaldehyde injury investigation were not available before the experiments of 1922 were started. Hence the soil moisture and the percentage of loss from formaldehyde injury were not determined.

C. A. Clark Farm Experiment, 1922

The experiment was repeated on the same field during 1922. Twenty-six rows 500 feet long, 12 inches apart were sowed at the rate of six pounds of seed per acre on April 26. The soil was dry and no rain fell during the next week which was windy, cool and dry. Different samples of formaldehyde were tried in which the percentage of methyl alcohol was extremely small (4 per cent.) or very high (16 per cent.). Also comparative tests were repeated with the 1–128–3000, 1–64–3000, 1–50–5000, and 1–50–4000. Formaldehyde injury was evident when the seed came up but unfortunately no records of its comparative extent or of the soil moisture conditions were made. The onions were harvested on August 25. The yield data are recorded in Table IV (p. 28). It will be noted from this table that the results are quite different from those obtained in 1920 on the same field (cf. Table II). The highest yields were secured with the dilute formula, 1–128–3000, while in 1920 it was the concentrated formulas, 1–32–3000 and 1–64–3000, which gave the highest yields. In 1920, the 1–50–5000 gave the lowest yield while in 1922 it was next to the best. This difference can be easily explained, however, in view of the difference in the moisture conditions of the soil at seeding time. The low yields obtained by the concentrated formulas like 1–50–3000 in 1922 were due to reduction of the stand through formaldehyde injury when the soil was very dry. They do not indicate a lack of control because, when less formaldehyde was used (1–50–5000) the yield was increased.

As to the effect of the methyl alcohol, the data show a much larger yield through the use of formaldehyde with a low percentage of methyl alcohol. Up to the present, however, the writers have not had opportunity to repeat this test and would hesitate to draw any conclusions from the results obtained on these two rows during one season.

Kuzmeski Farm Experiment, 1922

This was on the same field as was used in 1920. On April 25 when the seed was sowed the soil was very dry and continued so for the next week or more. The experiment included 16 rows, 220 feet long, 13 inches apart, seeded at rate of four pounds per acre. The observations throughout the summer coincided with those made on the C. A. Clark farm the same season. Smut was serious only in spots; therefore, the harvest data do not really show how complete was the control (since all the onions in the entire row were counted and therefore considerable stretches of row where there was little smut to control were included). In the worst places hardly any onions remained standing in the check row while there was a normal number in the treated rows. Only one dilution was used on this field but it was applied to the row at three different rates. The final results (presented in Table V (p. 28) confirm the conclusions drawn from the C. A. Clark farm experiment of the same year; viz., that the largest yield is obtained by using the 1–50–5000 formula, during a season when the seed must be sowed in a dry soil. The difference is due to formaldehyde injury and not to lack of control of smut.

The Objects of the Field Tests of 1923

Differences in yields secured by the various formulas in 1922 were the results of variation in (1) the control of smut and (2) the number of seeds prevented from

germinating by the formaldehyde. The presence of these two variables made the interpretation of the yields very uncertain. An effort was made in the experiments of 1923 to determine to what extent each of these factors was responsible for the variation in yield. This was accomplished by first determining the extent of the chemical injury. During the third or fourth week after planting, when it was thought that practically all the plants which would come up were visible and before any of them had disappeared from smut or damping off, the number of plants in each row was determined irrespective of whether they were diseased or not. Comparison of these with the untreated rows determined the extent of the chemical loss. The relative amount of loss from smut was determined at harvesting by subtracting the number of sound bulbs from the number of seedlings which escaped chemical injury. It is not thereby assumed that all the plants which died in the interim were killed by smut but that other agencies acted equally on all the rows. Also in order to check up under field conditions the influence of soil moisture at planting time, the percentage of moisture in the soil one inch below the surface was calculated for each experimental field on the day of planting.

Allen Clark Farm Experiment, 1923

This experiment was located in North Amherst on land heavily infested with smut at one end but very lightly at the other. It included 28 rows, 283 feet long, 13 inches apart, seeded at the rate of six pounds per acre. The ground was fairly moist, containing 17 per cent. water with a retentive capacity of 65 per cent. of the dry weight. It was planted on April 27 and there were heavy rains on the 28th and 29th. The rain probably came soon enough to affect the results of the treatment. Inspections while the onions were coming up and comparison by counting the seedlings at the end of a month showed the chemical injury to be negligible in this field. On September 4, when the onions were ready to harvest, the sound bulbs in 100 feet of each row on the more heavily infested end of the field were counted. The results, presented in Table VI (p. 28) are about what might be expected when the soil was neither extremely dry nor extremely wet. The highest yields were secured with the formulas of medium dilution (1–64–3000, 1–75–3000) or where the rate of distribution was medium (1–50–4000). None of the formulas failed to control, but the 1–50–5000 was least satisfactory. The appearance of the field four weeks before harvesting is shown in Fig. 2.

Kuzmeski Farm Experiment, 1923

This experiment was on the same field as the experiments of 1920 and 1922. It consisted of 24 rows, 436 feet long and 13 inches apart, seeded at the rate of six pounds per acre on April 21. The soil was extremely dry and dusty. A high wind during the day and the succeeding days kept the upper layer in the same condition for a week. The moisture was 6 per cent. and the retentive capacity 45 per cent. of the dry weight of the soil. All conditions were ideal for a high percentage of formaldehyde injury.

Examination when the onions were coming up and counting the number of seedlings when it was judged that all had come up, showed that the injury was certainly all that was predicted. On September 3 the number of sound bulbs remaining were counted. The data on this experiment are summarized in Table VII (p. 29). These data show that there was severe injury with all formulas used. The 1–50–5000 formula caused the least loss but that was 20 per cent. Even when the solution was diluted 1–100 there was a loss of 36 per cent. It is doubtful whether any practical formula can be used under these very dry conditions which will eliminate this loss. Under these conditions it is probably best to use the 1–50–5000 formula and increase the amount of seed enough to offset the formaldehyde injury.

Station Farm Experiment, 1923

This was the same field on which the experiment of 1919 was located. It consisted of 40 rows, 12 inches apart and 75 feet long, seeded on April 26 at rate of six pounds per acre. The soil was very dry and remained so for 48 hours after planting.

The moisture was 12 per cent. and the retentive capacity 64 per cent. of the dry weight. Such a condition was favorable for a high percentage of formaldehyde injury and when the onions came up the injury was apparent. The percentage of chemical loss was determined on June 1 and the yield data were taken on August 30. The data, presented in Table VIII (p. 29), show that the highest gain was obtained by the use of the 1-50-5000 formula and the next by the 1-64-3200 formula. The injury caused by the 1–50–3000 formula was so severe that there was an ultimate loss even though smut was controlled very effectively. On such a soil the 1-50-5000 formula is undoubtedly the best.

Conclusions from all of the Formaldehyde Experiments

After five years of experimentation, the writers came to some fairly definite conclusions in regard to the control of onion smut with formaldehyde. These conclusions, which will now be briefly stated, are supported by the data which have just been presented.

1. Smut can be controlled in any field in the Connecticut Valley and during any season by the use of a formaldehyde solution.

2. Extreme dilutions such as one part of formaldehyde in 128 parts of water, involving the use of a large amount of water, extra labor and inconvenience, are not necessary under the conditions which prevail here.

3. Within fairly wide limits, the control of smut is not dependent on the dilution, but on the actual amount of formaldehyde applied per unit distance of row. Thus, the concentration is not limited by lack of control, but by danger of injury to the seeds.

4. Any formula for the application of formaldehyde which is strong enough to control smut, also causes a certain percentage of the seeds to fail to germinate. This injury is especially noticed when the soil is very dry at planting time.

5. Formaldehyde injury varies inversely with the moisture content of the soil, and directly as the concentration of the solution and the amount of such solution applied per unit length of row.

6. The grower may reduce the loss from formaldehyde to a very small percentage and at the same time get better control of smut by changing his formula of application according to the moisture conditions of the soil on the day when the seed is planted.

7. From the standpoints of (a) profitable (but not necessarily maximum) prevention of smut, (b) minimizing the labor of drawing water, (c) ease of mixing the solution, (d) maximum reduction of the weight of water which must be carried on the drill, and (e) avoidance of severe chemical injury, we recommend the following as the most practical method of application:

If the soil is very dry, use the 1–50–5000 formula; if fairly moist, the 1–50–4000, and if wet, the 1–50–3000 formula.

Or this might be expressed to the grower thus:

Put one gallon of formaldehyde into a 50-gallon barrel and fill to the top with water. If soil is very dry, apply at rate of one barrel to one acre of onions (13 inches apart). If the soil is medium moist, apply 1¼ barrels, and if wet and heavy, 1⅜ barrels per acre.

8. On a dry soil the amount of seed per acre should be increased.

The Formaldehyde Tank for the Onion Drill

The formaldehyde solution is applied to the row from a tank attached to the seeder. Various kinds of tanks and methods of regulating the flow of the solution from them have been used and described by previous investigators (5:161).

In order that the control of smut be effective and injury reduced to the minimum it is important (1) that the rate of flow be uniform and (2) that the operator have some means of knowing just how much solution he is applying. These two requirements were doubly important for our experimental work.

In order that the data obtained might be reliable, a machine was needed which would distribute evenly and with a fairly high degree of accuracy any desired quantity of solution on a stated length of row. For this purpose the regulating apparatus on all of the machines which have been described before was found to be worth-

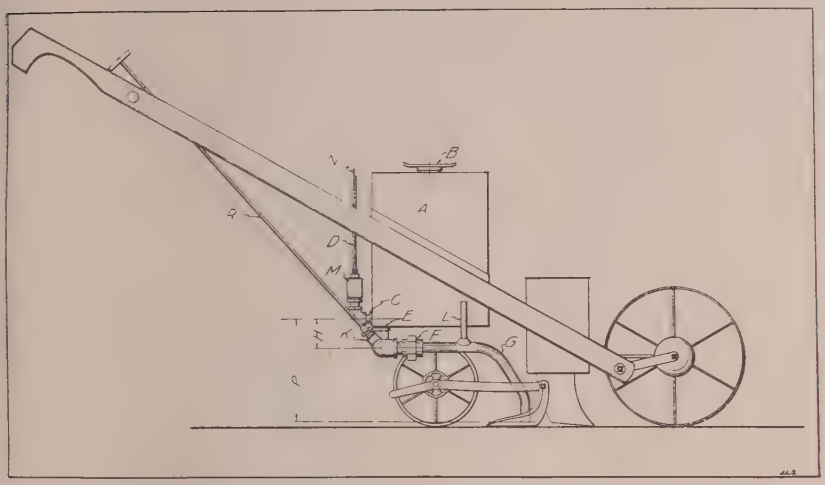

Fig. 5.—Mechanical drawing showing details of formaldehyde tank construction.

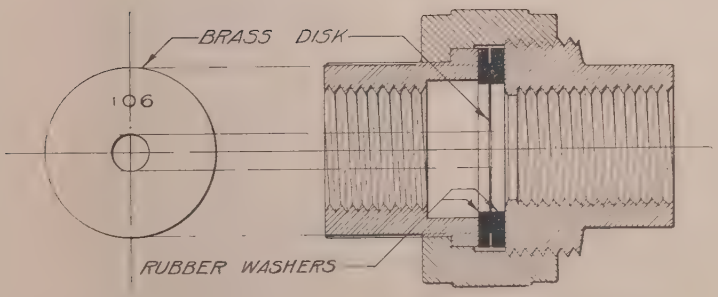

Fig. 6.—Sectional view of union in outlet pipe, with disk and washers in place.

less. None had a valve which could be set so that the operator would know when he started across the field how much solution would be applied per hundred feet. Actual tests of the different types of tanks showed considerable variation in the flow depending on how full the tank was. A 14-quart tank described below required more than twice as long to deliver the last quart as it did the first. The one-gallon copper tank first constructed by Stone (Mass. Agr. Expt. Sta. Circ. 21) — which is still in the possession of the Station—was tested and showed a difference in time of 15 per cent. between the first and last point. None of the tanks previously described has any method of correcting this error. None of them has any provision for eliminating the error due to variation in the speed of the operator. In short, there were so many sources of error and variation in all of the machines described up to the present that they were found to be utterly unsuitable for accurate research studies and a new tank and method of regulation had to be devised. The one which was finally evolved after experimenting with many different modifications is illustrated in Fig. 5 and described below.*

The tank itself (Fig. 5A) is a 14-quart cubical galvanized iron box attached between the handles of the drill just back of the seed box. The bottom of the tank is not flat but has a slight slope to a lowest point at the rear from which the solution is conducted through a ½-inch pipe (L) to the stopcock (K) and to the union (U). From there it is led through a ⅜-inch flexible block tin tube (G) and distributed on the seed and soil just back of the seed spout and in front of the coverers. The valve (K) is operated by a ¼-inch iron rod (R) from the rear end of the handles. It has nothing to do with the regulation of the flow but merely starts or stops the stream at the ends of the row or wherever desired.

The rate of flow from the tank is regulated by a series of brass disks with central apertures of graded sizes. A disk is held in place between rubber washers in the union of the outlet pipe (Fig. 6). Any number of these simple brass disks may be quickly cut out with tin shears from a sheet of brass. A hole is drilled through the center of each disk and this is enlarged with a rat-tail file to the proper size for the delivery of a gallon of solution in the previously calculated number of seconds which the operator wishes to use. The number of seconds required to deliver a gallon of solution is then stamped on the disk (Fig. 6). The size of the aperture needed depends on the formula of application which the operator wishes to use and the rate at which he walks. The number of disks which the experimenter or grower needs depends on the number of formulas he wishes to use, and the number of men, of different speeds of walking, who expect to push his drill. In our own experimental work seven different formulas of application were being tested and the drill was pushed at different times by three operators, the first one walking 4 feet per second, the second one 4½ feet per second and the third one 5 feet per second. Thus before the experiments were completed there were 21 disks. The operator could quickly find the proper disk by reference to a table attached to the side of the tank (Table 1).

TABLE 1.

Indicating the Disks of the Onion Drill to be Used According to the Speed of Workman and Formula Desired

Formula	4 Ft. per Sec.	4½ Ft. per Sec.	5 Ft. per Sec.
1– 50–3000	120	106	96
1– 50–4000	160	142	128
1– 50–5000	200	178	160
1– 32–3000	188	167	150
1– 32–4000	250	222	200
1– 64–3000	94	83	75
1–128–3000	47	42	37.5

*The authors are glad to acknowledge the very helpful cooperation of Professor C. I. Gunness and Professor J. L. Strahan of the Department of Rural Engineering, whose aid in the solving of some of the mechanical difficulties and the preparation of mechanical drawings, has been invaluable.

To illustrate: If the operator found that he walked at the rate of 4½ feet per second and he wished to use the 1–64–3000 formula, a glance at the table would tell him to insert in the union the disk stamped with the figure 83. Such a large number of disks will be needed only by the experimenter. The practical grower would not have occasion to use more than two or three and could make them as desired. This method of regulation was found to be very satisfactory and has the advantages of (1) permanent accuracy; no variation with wear or play; (2) cheapness and ease of construction within the reach of any grower; (3) simplicity; no complicated mechanism to be frequently out of repair; and (4) great elasticity, since a disk may be quickly made to suit any desired rate of flow.

The next modification was made for the purpose of correcting the variation in flow due to difference in head of the liquid as the quantity in the tank diminishes. All of the tanks which the writers have seen described have loose-fitting lids in the top through which the solution is poured to fill the tank. As the solution flows out through the outlet pipe the space which it leaves in the tank is immediately filled with air which comes in around the lid. Such an arrangement makes the rate of flow entirely dependent on the height of the water in the tank and as a result, the flow is much more rapid when the tank is full than when it is nearly empty. In order to determine the extent of such variation, the 14-quart tank just described was filled and the water permitted to run out with the lid loose or removed entirely. The time required for delivering each of the successive quarts was determined with a stop watch and the average of three tests is indicated in Table 2:

TABLE 2.

Rate of Flow of Each Successive Quart of Liquid from 14-Quart Tank (Open)

Quart	Seconds	Quart	Seconds
1	17.7	8	24.3
2	18.8	9	25.2
3	19.2	10	26.9
4	20.0	11	29.3
5	20.5	12	32.3
6	21.6	13	34.6
7	22.8	14	39.4

Thus, the operator who started with a full tank would be putting on the first part of the treated row double the amount which he put on the last part. The resulting control or injury would naturally show a similar variation. Data derived from the use of such a tank cannot be accurate. The variation in even the small tank described by Stone has been noted above. In order to make our control data reliable it was absolutely essential that this variation be eliminated. After considerable experimentation this was finally very successfully accomplished by modifying the tank thus: Instead of a loose-fitting lid, a screw cap (B), of 2-inch diameter (such as is commonly used on an automobile radiator) is used for closing the opening in the top. When screwed down with the shoulder against a rubber washer, this makes the top air-tight. A stand-pipe (D) parallel with and as high as the side of the tank is connected with the air vent (C) by means of an elbow.*

In this way, atmospheric pressure is maintained at the level of the vent (C) and consequently a uniform flow of solution is obtained irrespective of the height of water in the tank. The effective head producing the flow is always equal to (H). In order to prove that the flow is uniform, the outflow of each successive quart was timed just as described above but with the air-tight cap screwed down, and (with the No. 150 disk in the union) every quart from the first to the 14th flowed out in just 37½ seconds.

*In a later model this stand-pipe is built inside the tank and is simpler in construction but the principle is the same.

Two other modifications of minor importance have been added. In the enlarged base of the stand-pipe there is a float (M), which consists of a light hollow brass cylinder which has a "play" up and down of one inch. Attached to the top of this float is a slender brass wire stem (N) passing up through the narrow part of the stand-pipe and projecting an inch above the top of it when the float is up, just even with the top when the float is down. When the stream is running from the tank and everything is in order, the float is down and the stem does not appear above the top. If, however, there is any leak in the top of the tank or the operator has forgotten to screw down the cap, *i.e.*, if the tank for any reason is not air-tight, the water rises in the stand-pipe to the level in the tank, the float remains up and the projecting stem warns the operator that something is wrong. The float is thus a safety device and not an absolutely essential part.

The second modification is a very small pipe (L) about two inches long inserted on the upper side of the outlet pipe. This was added when it was discovered that for each of certain intermediate disks there were two distinct rates of flow. If the pipe below the union became immediately filled with water when the stream was turned on, it continued to come out in a steady stream and we had the faster rate of flow. Under these conditions the effective head would be (P) in the diagram. But at other times, even with the same disk, air gained access to this pipe and the water dribbled out. Then we had the slow rate of flow due to the head (H). Either flow remained constant but one never knew when he opened the valve which speed he would have. This difference in flow was eliminated when air was admitted to the outlet pipe through the small opening and pipe just mentioned.

With this improved tank just described all chances of error due to variation are eliminated except one. Variation in the rate of application might arise from variation in the speed at which the workman pushes the drill; *e.g.*, he might walk more slowly when he was tired or in softer land, etc. Numerous tests of the speed of different workmen at various times have convinced the writers, however, that a man's speed is remarkably constant and the error from this source is small. Nevertheless, it would be a distinct improvement if even this small error could be eliminated and the practical grower would be saved the trouble of measuring his speed and calculating the disk which he should use. This could be done if the apparatus were so constructed that the amount of solution delivered was proportionate to the distance travelled (*i.e.*, to the number of revolutions of the drill wheel) and not dependent on the length of time during which the valve is open. Then the rate of application would be entirely independent of the speed at which the drill was pushed. Such a regulating apparatus, geared to the drill wheel, is mechanically possible and its construction has been planned at various times by the writers. The construction has been abandoned for various reasons but principally because it would be too complicated and expensive and therefore less suitable for the average onion grower. For all practical purposes, and even for a fairly high degree of accuracy for experimental work, the apparatus described above is quite satisfactory.

MATERIALS OTHER THAN FORMALDEHYDE

One objection to the use of formaldehyde is the danger of injury to the seed under certain soil conditions which have been discussed previously. Although this can be largely avoided by changing the formula of application to suit the soil condition, growers cannot always be depended on to attend to this and some losses from this source are inevitable. It would be much better if we had a substitute which would give just as good control as formaldehyde, but without the attendant seed injury. In a search for such a substitute the writers have experimented with a list of chemical preparations, including Kalimat, Pythal, Furfural, Semesan, Uspulun, Germisan and several disinfecting powders manufactured by the Du Pont Company and by the Corona Chemical Division of the Pittsburgh Plate Glass Company. All of these were found to have some merit in decreasing the amount of smut, but for the most part the control was inferior to that secured by formaldehyde. Kalimat, however, is a notable exception. It was tested for two years in the field and in the greenhouse in pots where the soil moisture was controlled. These experiments and the results are described in detail in a separate publication (3). It is sufficient here

to present the data on the experiments of 1924 (Table IX, p. 29) and the conclusions from the results of the two years' experiments.

"In all tests during the last two years, kalimat has controlled onion smut just as well as formaldehyde. It is superior to formaldehyde, however, not on account of its fungicidal properties but on account of its comparative safety when used in concentrated solutions or when used in very dry soils. Under these same conditions formaldehyde frequently causes serious injury.

"The claim of the manufacturers that the percentage of germination is increased by the use of kalimat would seem at first to have some support in the data presented. Of the 14 comparisons between treated and check rows, 10 show that there were more seedlings on the treated than on the untreated rows. This does not necessarily mean, however, that kalimat stimulated germination of the seeds; it may have merely killed off some organisms which naturally destroy the seedlings before they reach the surface of the soil.

"The only objection to the use of kalimat is that it is rather expensive at present. It may be obtained for about $1.00 per pint. In larger quantities, however, it could probably be obtained at a lower price. If any considerable demand for it should be developed, the cost of production will be lowered or other substances embodying the same protective principle will appear on the market.

"Of the formulas tried, probably the 1–50–4000 could be recommended as giving excellent control and as being economical of labor and material. This would require about five quarts of kalimat per acre of onions when the rows are thirteen inches apart. In extremely dry soil the same amount applied in greater dilution might have some advantage."

Uspulun. This is a patented German chemical preparation marketed in the form of a purplish gray powder, readily soluble in water to form a purple solution. The active fungicidal principle is orthochlorphenol. In preliminary greenhouse experiments 1 per cent. and 2 per cent. were tried in the formulas 1-50-3000, 1–50–4000, 1-50-5000, 1-100–3000, 1–100-4000 and 1-100-5000. Fair control was secured with all formulas but the best with 1–100-3000. In the field experiments of 1924 the formulas of 1-50-3000 and 1–100-3000 were each used on one row 70 feet long. The percentage of control was just as high as that secured by kalimat or formaldehyde. There was no evidence of seed injury or stunting and the percentage of germination was higher than on the check rows. The results were sufficiently promising to warrant the further testing of this substance. The results will be described more in detail after further tests under different conditions.

Germisan. This is also a German patented disinfectant marketed in the form of a powder but to be used in solution. It has been tried only in our field experiments of 1924 and in the formulas 1–50–3000, 1–50-4000 and 1–50–5000. All formulas gave increased germination and good control of smut. The weakest formula gave just as good control as the others. These results look promising, but we hesitate to make any recommendations until the material has been tried under other conditions.

The other chemical solutions tried gave a percentage of control much lower than formaldehyde.

Dry Chemicals. If some effective and comparatively cheap substance could be found which could be applied as a dry powder it would present certain advantages over solutions: (1) it would eliminate the labor of drawing barrels of water to the field, (2) it would make the drill easier to push because of elimination of the weight of the water, (3) it would eliminate the danger of clogging the seed spout and packing wheel with mud, and (4) machinery for application would probably be simpler and cheaper.

A number of these dry preparations have been tried by the writers but only one up to the present has given a high enough percentage of control to encourage further trials. This is a powder prepared especially for this kind of work by the Corona Chemical Division of the Pittsburgh Plate Glass Company and furnished to the writers under the label "Corona 640." In the preliminary greenhouse tests, this gave better control than any of the others and was, therefore, selected for the field tests of 1924. This was in badly infested soil but at the end of the season the row to which this material was applied contained as many healthy onions as any of the rows treated with the other preparations. There was also an increase in the number

of seedlings which came up. Further investigations are now in progress to determine whether the results will be repeated under different conditions and to perfect simple machinery for application.

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APPENDIX

TABLE I.

Cowls Farm Experiment, 1919

Treatment Formula	100 Ft. of Row on June 2			100 Ft. Harvested September 15				Gain in Pounds per Acre
	Standing Onions	Per Cent. Smut	Total Gain in Healthy Plants	Number Onions Harvested	Gain in Bulbs	Weight in Pounds	Gain in Lbs.	
1- 64-3200	2120	11.3	1222	773	596	105	66	26,400
1- 96-3200	2256	12.8	1308	844	667	116	77	30,800
1-128-3200	1923	17.7	825	936	759	112	73	29,200
Untreated	1325	50.4		177		39		

TABLE II.

C. A. Clark Experiment, 1920

Treatment Formula	Feet of Row Treated	Average Harvest for 100 Ft.				Gain in Pounds per Acre
		No. of Bulbs Harvested	Gain Over Check	Weight of Bulbs Harvested (Pounds)	Gain in Pounds Over Check	
1-128-3000	1068	736	301	120	42	18,295
1- 96-3000	1068	769	334	121	43	18,731
1- 64-3000	1068	782	347	122	44	19,166
1- 48-3000	1068	686	251	117	39	16,988
1- 32-3000	534	758	323	125	47	20,473
1- 50-4000	534	694	259	114	36	15,682
1- 50-5000	534	615	180	108	30	13,068
Untreated	2136	435		78		

TABLE III.

Kuzmeski Farm Experiment, 1920

Treatment Formula	Feet of Row Treated	Average Harvest for 100 Ft.		Percentage of Increase
		Number of Bulbs Harvested	Gain in Bulbs Over Check	
1-96-3000	3488	849	493	137
1-50-5000	3488	610	254	72
Untreated	1744	356		

TABLE IV.

C. A. Clark Experiment, 1922

Treatment Formula	Percentage Methyl Alcohol	Feet of Row Treated	Average of 100 Feet		Percentage of Increase
			No. Bulbs Harvested	Gain in Bulbs Over Check	
1– 50–3000	6–14	2000	230	54	30
1– 50–3000	4	1000	288	112	64
1– 50–3000	16	1000	234	58	33
1– 50–4000	6–14	2000	238	62	35
1– 50–5000	6–14	2000	285	109	62
1– 64–3000	6–14	1000	268	92	53
1–128–3000	6–14	1000	303	127	72
Untreated		3000	176		

TABLE V.

Kuzmeski Farm Experiment, 1922

Treatment Formula	Feet of Row Treated	Average Harvest for 100 Feet		Percentage of Gain
		No. of Sound Bulbs	Gain in Bulbs Over Check	
1–50–3000	880	580	203	53
1–50–4000	880	576	199	53
1–50–5000	880	699	322	85
Untreated	880	377		

TABLE VI.

Allen Clark Farm Experiment, 1923

Treatment Formula	Feet of Row Treated	Average Harvest for 100 Feet		Percentage of Gain
		No. of Sound Bulbs	Gain Over Check	
1– 64–3000	1132	737	611	485
1– 75–3000	1132	733	607	482
1– 50–3000	1132	565	439	350
1–100–3000	1132	677	551	437
1– 50–4000	1132	721	595	472
1– 50–5000	566	339	213	169
Untreated	1698	126		

TABLE VII.

Kuzmeski Farm Experiment, 1923

Treatment Formula	Feet of Row Treated	Per Cent. Chemical Loss	Average Harvest on 100 Feet		
			No. of Sound Bulbs	Gain Over Check	Per Cent. Shrinkage June 1 to Sept. 3
1– 50–3000	1744	57	299	– 8	29
1– 50–4000	1744	51	262	–45	33
1– 50–5000	1744	20	338	31	38
1– 64–3000	872	41	285	–22	40
1– 75–3000	872	32	356	49	35
1–100–3000	872	36	314	7	36
Untreated	2616		307		62

TABLE VIII.

College Farm Experiment, 1923

Treatment Formula	Feet of Row Treated	Per Cent. Chemical Loss	Per Cent. Shrinkage June 1—Aug. 30	Final Gain Over Check per 100 Feet
1– 50–3000	300	70	25	–31
1– 50–4000	300	49	39	23
1– 50–5000	300	30	33	95
1– 64–3000	300	72	28	63
1– 75–3000	150	60	31	7
1–100–3000	300	48	40	22
Untreated	975		73	

TABLE IX.

Comparison of Kalimat and Formaldehyde in the Field Tests of 1924
Each Row 70 Feet Long

Chemical	Formula	Number of Rows Treated	Average Number of Seedlings Which Came up per Row	Average Sound Onions Harvested per Row
Check		12	539	122
Kalimat	1– 50–5000	8	544	340
Formaldehyde	1– 50–5000	8	538	309
Kalimat	1– 50–4000	8	625	432
Formaldehyde	1– 50–4000	8	525	331
Kalimat	1– 50–3000	4	516	380
Formaldehyde	1– 50–3000	4	469	285
Kalimat	1–100–3000	4	593	331
Formaldehyde	1–100–3000	4	416	293